Abstract—Bio-available phosphorus (BAP) is a new criterion for evaluating water quality, so controlling BAP export has significant meaning for non-point pollution. Phosphorus—transporting dynamics under three gradients and rainfall intensities were simulated. The study showed that BAP increased with rainfall intensity and gradient increasing. Sediment extractable bio-available phosphorus (BPP) concentrations of overland flow were between 0.065—0.115mg/L. Crop coverage could reduce the fluctuation of overland flow and subsurface runoff, and subsurface runoff could decrease the flux and BAP export through overland flow. BPP was absorbed by sediment and BPP of subsurface runoff was mainly through sediment transportation. Relationship between BAP concentration(y) and flux(x) could be expressed by: y=0.0144Ln(x) + 0.0074 ($r^2=0.9014$). The maximum BAP loss rate of sloping cropland of purple soil reached 0.296g/hm$^2$ and the maximum soil loss rate reached 4461.89 kg/hm$^2$. Therefore, it is very important to evaluate the eutrophication of local water environment and analyze the overall effect of subsurface runoff.

Keywords—Simulated rainfall; BAP; BPP

I. INTRODUCTION

Since P is one of factors causing eutrophication, transportation of phosphorus of sloping cropland, should be controlled in order to improve soil quality [1,2]. Total Phosphorus (TP) and Dissolved Phosphorus (DP) have been used to evaluate the impact of P loss on water, but a part of P couldn’t be absorbed and utilized by biology and no impact on water quality. Therefore, bio-available phosphorus (BAP) is used to evaluate water quality; BAP is the potential P that could be absorbed and utilized by alga and it comprise of DP and BPP [3].

Minimizing water body eutrophication from agricultural non-point resource pollution often requires controlling P inputs to surface water [4,5]. In the Netherlands, the national strategy for minimizing non-point pollution is to limit entry of P into both surface and groundwater [6]. BAP is an important contributing factor causing lakes eutrophication [3], and it comprise a larger portion of TP loss (25 to 30%) for both fertilized and unfertilized conditions [7].

Purple soil has a rich mineral composition, good cultivating capability and productivity, high natural fertility, so it is a good precious agricultural soil resource in China [8]. Since there are few reports about the exporting dynamics of BAP of purple soil through overland flow and subsurface runoff, the objectives of research was to study the course, mechanism and influencing factors of BAP transporting from sloping cropland of purple soil under different intensities and gradients. It could provide scientific basis for controlling the export of non-point source pollutant from the hilly area of purple soil and establishing the monitoring model for Three Gorge Reservoir Area further.

II. MATERIALS AND METHODS

Description of Site

The experimental site is located at Yanting agro-ecological experimental station, Chinese Academy of Sciences, in the middle of Sichuan Basin (105° 27’ E, 31° 16’ N); the station stands between the Zi River and the Jialing River, both of which are the branches of Pu River, which are two branches of Pu River. The average annual rainfall of Yanting station is about 825 mm, but most rainfalls are focused on summer.

Properties of Tested Soil

The tested soil was calcareous purple soil, neutral texture, clay particle< 20%, silt between33.1% and 43.8%, bulk weigh 1.3± 0.03 g/cm$^3$, PH values 8.1±0.2, TP 0.81± 0.3 g/kg, available P 44.72± 5.91 mg/kg, organic matter 7.8± 0.7 g/ kg and water content 16.60± 1.0% [9], and analysis method saw Lao [10].

Experiment Design

The American Norton swing devices were used to simulate rainfall. The height of rainfall was 2.7 m, and experimental plot was steel groove connecting with two barrels that gathered overland flow and subsurface runoff respectively, and the standard was: length $\times$ width $\times$ height = 5.0m $\times$ 1m $\times$ 0.5m. The gradients of grooves were 5°, 10° and 15° (the farmland gradients of purple soil area in China were generally 3°-15°); surface condition was about 80% crop coverage (planting corn); the fertilization of plots were 0.088 kg/m$^2$ pure nitrogenous fertilizer and 0.075 kg/m$^2$ pure phosphate fertilizer being close to local fertilization and the method of fertilization was through application in the planting holes [11], and the time of fertilization was 25-30 days before simulated rainfall; rainfall intensities covered moderate rain (0.33 mm/min), downfall (0.9 mm/min) and rainstorm (1.86 mm/min), and rainfall time lasted about 90-150min and stop sampling until overland flow and subsurface runoff was stable. The canvas was used to keep the wind...
out, and the water of rainfall came from tap water which should be sampled to analyze BPP and DP before rainfall. If there were natural rainfall, the simulated rainfall experiments would be delayed 24h after natural rainfall stopping. The experiment was done during July 2006 to August 2006. The water content of sloping cropland before simulate rainfall could see Table 1.

### TABLE 1. WATER CONTENT OF SLOPING CROPLAND MEASURED BEFORE SIMULATED RAINFALL

<table>
<thead>
<tr>
<th>Cropland Type</th>
<th>Water Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>Downfall</td>
</tr>
<tr>
<td>5°</td>
<td>28.2</td>
</tr>
<tr>
<td>10°</td>
<td>30.4</td>
</tr>
<tr>
<td>15°</td>
<td>32.4</td>
</tr>
</tbody>
</table>

**Sampling and Analytical Method**

The beginning times of overland flow and subsurface runoff were measured after rainfall, and the samples should be collected every 1~3 min. The sampling time might be prolonged as the runoff being stable and the total runoff samples were collected at last. The BPP and DP of samples were analyzed and the phosphorus contents of overland flow and subsurface runoff could be obtained through subtracting the background of tap water. The water samples were filtered through 0.45-µm membrane. DP was determined by spectrophotometric analysis with the reduction of ascorbic acid and chromogenic reaction of ammonium molybdate and antimony trichloride. Sediment was air-dried after filtering and extracted by NaHCO₃, then boiled by HClO₄-H₂SO₄, and BPP was determined by the same method as DP. The extraction and chromogenic reaction must be kept at constant temperature 20 ~ 25° [12]. BAP was equal to BPP plus DP.

III. RESULTS AND DISCUSSION

**Runoff Dynamics**

Figure 1 shows the change of overland flow and subsurface runoff under three gradients and rainfall intensities. When 5° sloping cropland was moderate rain, there was not big discrepancy between overland flow and subsurface runoff. This was because rainfall intensity and gradient were small, it was not easy to form overland flow and a great part of rain formed subsurface runoff through infiltration. But there were significant difference on overland flow and subsurface runoff at the other rain events. Since gradient and intensity increasing, a plenty of rain flowed out through overland flow when subsurface runoff have not formed. The flux of subsurface runoff was between 3 ~ 10mL/s at different rainfall events. The flux of subsurface runoff was not evidently influenced by different gradient and rainfall intensity, only 2 ~ 3mL/s discrepancy. Because the subsurface runoff began to export by gravity function only after the interstices saturated, and bulk weight and porosity were important restricting factor for conducting flow [13]. Different gradients and intensities mainly impacted on the saturated time of interstices and the subsurface runoff-yielding time. Subsequently gradient and intensity were bigger, the subsurface runoff - yielding time would be earlier.

At different rainfall events, the exporting dynamics of overland flow was increasing gradually, then decreasing and reaching stable gradually during the later period of runoff as a whole. When the gradient and intensity were bigger, the overland flow-yielding time was earlier. Lawrence and Schlesinger thought crop coverage could delay runoff-yielding time, and promote subsurface runoff [14]; Huang thought the runoff-yielding time may be related to the different water content of soil in the rainfall phase, because the higher water content would be helpful to improve diffusion function [15]. The experiment of crop coverage and water content were not distinct discrepancy, so the coverage and water content have no impact on overland flow and subsurface runoff, so the gradient and rainfall intensity were main factor for simulated experiment.

**BPP Dynamics**

At different rainfall events, the BPP concentrations of overland flow were between 0.065 ~ 0.115mg/L, and the BPP concentration of subsurface runoff was 30 ~ 45% of that through overland flow (Fig.2). There was significant difference on overland flow and subsurface runoff because of the interior water of soil influenced phosphorus transport and the phosphorus loss of sloping cropland was mostly through overland flow [2,16]. The BPP dynamics of overland flow and subsurface runoff was stable as a whole. This is because the crop as isolating layer could avoid the direct striking of rain and alleviate the overland flow and lead to sub-filter slowly [13].

**DP Dynamics**

The DP concentrations of overland flow were not all bigger than subsurface runoff. The DP concentrations of overland flow and subsurface runoff were ranging from 0.001 ~ 0.015mg/L (Fig.3). The DP concentrations of overland flow were 4 ~ 10% of its BPP concentration, and the DP concentrations of subsurface runoff were 10 ~ 20% of its BPP concentration. The DP/BPP values of subsurface runoff were bigger than overland flow. Gradient or intensity didn’t show prominent impact on DP export. This phenomenon could be explained that phosphorus was absorbed by soil particles strongly and released from soil particles reached the highest volume after 2h, and when the water/soil ratio was equivalent, there was not significant difference on phosphorus releasing [17,18].

**Phosphorus Transport Comparison**

The BPP concentrations of overland flow and subsurface runoff changed regularly, and the BPP exporting volume increased with rainfall intensity and gradient going up (Table 2). Besides relating with phosphorus releasing extent of soil particles, DP concentration wasn’t evidently influenced by gradients and intensities. The BPP/BAP ratios were above 80%, and the BAP was mainly through BPP export. Under the same gradient and rainfall intensity, the total flux of subsurface runoff was about 10 ~ 15% of that through overland flow and the BAP exporting volume of subsurface runoff was about 3 ~ 10% of that through overland flow. Yielding subsurface runoff could reduce the runoff discharge and BAP export from overland flow and the function of subsurface runoff for decreasing overland flow was more prominent.

Subsurface runoff contained a few amount of sediment and it was main way that the BPP of subsurface runoff transported. Sediment loss was related with rainfall intensity, rainfall time, gradient and crop coverage, and so on. When rainfall intensity, gradient and rainfall time were rainstorm, 15° and rainfall 210.18, respectively, the maximum soil loss rate of cropland could reach 4461.89 kg/hm². Xu and Zhu [19] thought that the relationship between phosphorus transporting of runoff and intensity was prominent. Because of phosphorus transporting through runoff largely, the relationship between runoff and BAP export may exist pertinence. Through logarithmic analysis, the relationship between BAP exporting concentration(y) and flux(x) could be expressed by: y = 0.0144Ln(x) + 0.0074 (r²=0.9014).
IV. CONCLUSION

The study provided evidences that the BPP exporting concentrations of subsurface runoff were about 30~45% of that through overland flow. Crop coverage could reduce the fluctuation of overland flow and subsurface runoff, and subsurface runoff could decrease the flux and BAP export of overland flow. Gradient and intensity didn’t show prominent impact on DP concentration. Subsurface runoff contained a few amount of sediment, which was main way that BPP of subsurface runoff transported. When rainfall intensity, gradient and rainfall time were rainstorm, 15° and rainfall 210.18, respectively, the maximum of BAP loss rate of sloping cropland could reach 0.296g/hm², and the maximum of soil loss rate could reach 4461.89 kg/hm². So it could be forecast that the great rainfall easily caused phosphorus and sediment loss largely in purple soil watershed, and lead to eutrophication in local water-bodies and seriously influence on the water quality of life and production.

Because the gradient, soil condition, fertilization and crop coverage that the experiment simulated had quite high representative for purple soil area in China, the experiment results were quite high reliable and revealed the local status of non-point source pollution rightly. The manner of fertilization is mainly the method of application in the planting hole, so the fertilizer is easily absorbed by crop, and the utilizing rate of fertilizer is higher and the effective time is longer. As for other manners of fertilization and cultivation, the loss mechanism and transport amount of phosphorus need to be studied further in the future.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES


Figure 1. Overland flow and subsurface runoff dynamics of 5°, 10° and 15° sloping cropland under moderate rain (A), downfall (B) and rainstorm (C).
Figure 2. Change of BPP concentration through overland flow and subsurface flow of 5°, 10° and 15° sloping cropland under moderate rain (A), downfall (B) and rainstorm (C).

Figure 3. Change of DP concentration through overland flow and subsurface flow of 5°, 10° and 15° sloping cropland under moderate rain (A), downfall (B) and rainstorm (C).

TABLE II. PHOSPHORUS TRANSPORT OF OVERLAND FLOW AND SUBSURFACE RUNOFF AT DIFFERENT RAINFALL EVENTS.

<table>
<thead>
<tr>
<th>Slope Type</th>
<th>Runoff Type</th>
<th>Flux (L)</th>
<th>BPP (mg/L)</th>
<th>DP (mg/L)</th>
<th>BAP (kg/hm²)</th>
<th>BPP/BAP (%)</th>
<th>Sediment (kg/hm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.35 5° Moderate Rain</td>
<td>Overland</td>
<td>111.52</td>
<td>0.071</td>
<td>0.0108</td>
<td>0.0365</td>
<td>87</td>
<td>713.73</td>
</tr>
<tr>
<td>31.35 5° Subsurface</td>
<td>Overland</td>
<td>13.59</td>
<td>0.033</td>
<td>0.0138</td>
<td>0.0025</td>
<td>81</td>
<td>6.98</td>
</tr>
<tr>
<td>5° 74.7 Downfall</td>
<td>Overland</td>
<td>149.01</td>
<td>0.075</td>
<td>0.0038</td>
<td>0.0470</td>
<td>95</td>
<td>953.66</td>
</tr>
<tr>
<td>5° Subsurface</td>
<td>Overland</td>
<td>16.26</td>
<td>0.036</td>
<td>0.0051</td>
<td>0.0027</td>
<td>88</td>
<td>8.06</td>
</tr>
<tr>
<td>5° 158.1 Rainstorm</td>
<td>Overland</td>
<td>535.43</td>
<td>0.078</td>
<td>0.0056</td>
<td>0.179</td>
<td>93</td>
<td>3426.75</td>
</tr>
<tr>
<td>5° Subsurface</td>
<td>Overland</td>
<td>17.98</td>
<td>0.039</td>
<td>0.0033</td>
<td>0.0031</td>
<td>83</td>
<td>11.07</td>
</tr>
<tr>
<td>5° 26.07 Moderate Rain</td>
<td>Overland</td>
<td>11.71</td>
<td>0.037</td>
<td>0.0044</td>
<td>0.00194</td>
<td>89</td>
<td>5.94</td>
</tr>
<tr>
<td>10° 102.6 Downfall</td>
<td>Overland</td>
<td>320.45</td>
<td>0.081</td>
<td>0.0056</td>
<td>0.111</td>
<td>94</td>
<td>2050.88</td>
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<tr>
<td>10° Subsurface</td>
<td>Overland</td>
<td>19.41</td>
<td>0.037</td>
<td>0.005</td>
<td>0.0033</td>
<td>88</td>
<td>10.22</td>
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<tr>
<td>10° 252.96 Rainstorm</td>
<td>Overland</td>
<td>323.71</td>
<td>0.085</td>
<td>0.0088</td>
<td>0.213</td>
<td>91</td>
<td>3634.94</td>
</tr>
<tr>
<td>10° Subsurface</td>
<td>Overland</td>
<td>25.35</td>
<td>0.045</td>
<td>0.0105</td>
<td>0.0056</td>
<td>81</td>
<td>12.24</td>
</tr>
<tr>
<td>10° 37.95 Moderate Rain</td>
<td>Overland</td>
<td>72.94</td>
<td>0.082</td>
<td>0.004</td>
<td>0.0251</td>
<td>95</td>
<td>466.82</td>
</tr>
<tr>
<td>15° 104.8 Downfall</td>
<td>Overland</td>
<td>20.38</td>
<td>0.045</td>
<td>0.0027</td>
<td>0.00227</td>
<td>88</td>
<td>8.14</td>
</tr>
<tr>
<td>15° Subsurface</td>
<td>Overland</td>
<td>12.21</td>
<td>0.041</td>
<td>0.0054</td>
<td>0.00227</td>
<td>88</td>
<td>8.14</td>
</tr>
<tr>
<td>15° 210.18 Rainstorm</td>
<td>Overland</td>
<td>23.89</td>
<td>0.047</td>
<td>0.0093</td>
<td>0.0054</td>
<td>83</td>
<td>13.90</td>
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